Scoring Key
Unit 1: Kinematics

Fifty-two rubric points across the five free-response problems of Chapter 1 — and, at each one, the shortest answer that still earns it.

What this key is for

A suggested way to score problems 1.1–1.5 of the AP Physics 1 workbook, to help teachers grade them quickly and consistently. The format follows College Board's published scoring guidelines, but the points and thresholds are this book's own reading of the standard — another reader might draw a line differently.

How to read one point

Every point carries four things, in this order.

For ... The condition. One sentence saying what the response must contain. The label on the right — Point A1 — names the point; the letter is the part of the problem.

Scoring Note A ruling on an edge case: what two parts may be scored together, which errors are carried forward, what a bare final answer is worth.

Example Response A full-credit answer. It is a model, not a threshold — a response can be much thinner than this and still earn the point.

Minimum sufficient **The threshold.** The least a student can put on the page and still be given the point, plus, where it matters, the near-miss that sits just below it. This is the line published guidelines leave to the reader's judgement; here it is written down so that twenty-five papers can be graded in a quarter of an hour and graded the same way twice.

Three standing rules. A point is earned independently of those around it unless a Scoring Note says otherwise; an error made early and carried through consistently is scored as correct downstream; and a bare answer earns the points its Scoring Note names, never more.

What each problem is worth

The totals are not free choices. They are the point values the 2025 exam gives each question type — ten, twelve, ten and eight, forty on the paper. Chapter 1 carries one problem of each type plus a second Translation problem, so the chapter runs to fifty-two.

PROBLEM	TYPE	WHAT IT TESTS	POINTS
1.1	MR	Projectile motion; independence of the horizontal and vertical motions; why mass drops out	10
1.2	TBR	Constant velocity against constant acceleration, read off a motion diagram and an x–t graph	12
1.3	LAB	Designing a kinematics experiment; linearising d against t^2 to get acceleration from a slope	10
1.4	QQT	Free fall; turning a scaling claim into a functional dependence $h \propto v_0^2$	8
1.5	TBR	Relative motion on a moving walkway; velocity addition and frame-dependent graphs	12
		Chapter 1 total	**52**

MR Mathematical Routines • **TBR** Translation Between Representations • **LAB** Experimental Design and Analysis • **QQT** Qualitative Quantitative Translation.

Problem 1.1: Mathematical Routines (MR) — 10 rubric points

The problem. A ball is launched horizontally from the edge of a cliff of height H with initial speed v_0; air resistance is negligible. It lands a horizontal distance D from the base of the cliff.

Part (a) i *Draw and label, on a dot, arrows for the forces exerted on the ball while it is in the air.*

For a single downward arrow, labelled as the gravitational force, drawn from the dot — and no other arrow. **Point A1**

Accept any of these labels:

- F_g, $\vec{F}_g$, mg, or $m\vec{g}$
- weight, gravity, gravitational force
- force of Earth on the ball

Scoring Note. The "and no other arrow" clause is part of this point, not a separate one. A second arrow forward along the velocity — a "force of motion" — costs the point even though the downward arrow is drawn correctly. Components in place of the force itself also cost it.

EXAMPLE RESPONSE

One arrow from the dot pointing straight down, labelled $\vec{F}_g = m\vec{g}$. Nothing else on the dot.

MINIMUM SUFFICIENT One downward arrow carrying any of the labels above, with nothing else drawn. **Not enough:** an unlabelled downward arrow — the question asks the student to *label* the arrow, and an unlabelled one cannot be told from a velocity or an acceleration.

Part (a) ii *Derive an expression for the time t to reach the ground, beginning from a fundamental principle or a reference equation.*

For opening the derivation with a constant-acceleration relation linking vertical position and time. **Point A2**

Accept one of the following:

- $y = y_0 + v_{y0}\,t + \frac{1}{2}a_y t^2$
- $\Delta y = v_{y0}\,t + \frac{1}{2}a_y t^2$
- $\Delta y = \bar{v}_y\,t$ together with $v_y = v_{y0} + a_y t$

EXAMPLE RESPONSE

$y = y_0 + v_{y0}\,t + \frac{1}{2}a_y t^2$, written out for the vertical motion with up taken as positive and the origin at the launch point.

MINIMUM SUFFICIENT The general equation on the page *before* anything is put into it. **Not enough:** naming it in words — "I used the position equation" — with no equation written.

For the two substitutions that carry the physics: zero initial vertical velocity, and a vertical displacement of magnitude H under an acceleration of magnitude g. **Point A3**

Scoring Note. Either sign convention is fine so long as it is used consistently; what is being scored is $v_{y0} = 0$ and $|\Delta y| = H$, not the signs.

EXAMPLE RESPONSE

Taking up as positive with the origin at the launch point, $-H = 0 + (0)t + \frac{1}{2}(-g)t^2$, so $H = \frac{1}{2}gt^2$.

MINIMUM SUFFICIENT $H = \frac{1}{2}gt^2$ on the page, in either sign convention. **Not enough:** substituting $v_{y0} = v_0$ into the vertical equation. The launch is horizontal, so the whole of v_0 is horizontal; this is the error that ends the problem.

For a correct expression for the time in terms of H and g. **Point A4**

Scoring Note. A bare $t = \sqrt{2H/g}$, with nothing written above it, carries A3 as well: there is no route to that expression that does not set the initial vertical velocity to zero. A2 stays unearned — that point pays for showing where the equation came from.

> **EXAMPLE RESPONSE**
>
> $$t = \sqrt{\frac{2H}{g}}$$

> **MINIMUM SUFFICIENT** $t = \sqrt{2H/g}$, with no working required. **Not enough:** stopping at $t^2 = 2H/g$. The question asks for t.

Part (a) iii *Derive an expression for the horizontal distance D.*

For using a constant-velocity relation horizontally, with the horizontal acceleration taken as zero. **Point A5**

Accept one of the following:

- $D = v_0 t$
- $x = x_0 + v_x t$ with $v_x = v_0$
- $v_0 = D/t$

> **EXAMPLE RESPONSE**
>
> Nothing accelerates the ball horizontally, so $a_x = 0$ and $x = x_0 + v_x t$. With $x_0 = 0$, $x = D$ and $v_x = v_0$, this is $D = v_0 t$.

> **MINIMUM SUFFICIENT** The equation $D = v_0 t$ anywhere in this part. No statement that $a_x = 0$ is required — writing the constant-velocity form is the statement.

For a final expression for D consistent with the time expression of part (a) ii. **Point A6**

> **EXAMPLE RESPONSE**
>
> $$D = v_0\sqrt{\frac{2H}{g}}$$

> **MINIMUM SUFFICIENT** $D = v_0\sqrt{2H/g}$. If part (a) ii produced a wrong time, this point is still earned when that wrong time is substituted here correctly — score consistency, not the answer.

Part (a) iv *Calculate D for $H = 45\,\mathrm{m}$ and $v_0 = 12\,\mathrm{m/s}$.*

For a numerical value of D near $36\,\mathrm{m}$, with the given values substituted. **Point A7**

Scoring Note. Accept $35\,\mathrm{m}$ to $37\,\mathrm{m}$. The spread is the choice of g: $g = 9.8\,\mathrm{m/s^2}$ gives $36.4\,\mathrm{m}$ and $g = 10\,\mathrm{m/s^2}$ gives $36.0\,\mathrm{m}$. Score consistently with the student's own expression from (a) iii.

> **EXAMPLE RESPONSE**
>
> $$D = (12\,\mathrm{m/s})\sqrt{\frac{2(45\,\mathrm{m})}{9.8\,\mathrm{m/s^2}}} = (12\,\mathrm{m/s})(3.03\,\mathrm{s}) \approx 36\,\mathrm{m}$$

> **MINIMUM SUFFICIENT** A number between 35 and 37 carrying the unit m. The substitution need not be shown. **Not enough:** a bare "36" with no unit.

Part (b) *A second ball of mass $2m$ is launched from the same cliff at the same speed. Is its horizontal distance greater than, less than or equal to D? Justify using physical principles.*

For selecting "Equal to." **Point B1**

Scoring Note. Scored on its own. The student keeps this point even if the justification below it is wrong or missing.

> **EXAMPLE RESPONSE**
>
> *Equal to.* (The wrong selection students reach for is *Less than*, on the picture of a heavier ball dropping away sooner.)

MINIMUM SUFFICIENT The blank under "Equal to" marked. Nothing written elsewhere is needed.

For a justification that the two balls accelerate at the same rate whatever their masses. **Point B2**

Accept one of the following:

- $a = F_g/m = mg/m = g$, so the mass cancels
- the gravitational force grows in proportion to the mass and so does the inertia, so the two effects cancel
- both balls are in free fall, and free-fall acceleration does not depend on mass

EXAMPLE RESPONSE
The only force on either ball is the gravitational force $F_g = mg$. Newton's second law then gives $a = F_g/m = g$, so both balls accelerate downward at g no matter what they weigh.

MINIMUM SUFFICIENT "$a = mg/m = g$" written out, or the sentence "free-fall acceleration does not depend on mass." **Not enough:** "gravity is the same for both." That names the force, which is in fact *not* the same — the heavier ball is pulled harder. The claim that scores is about the *acceleration*.

For carrying mass-independence through to the horizontal distance itself. **Point B3**

Accept one of the following:

- the derived expression $D = v_0\sqrt{2H/g}$ contains no mass
- the flight time and the horizontal speed are both unchanged, so D is unchanged
- launched at the same speed from the same height, the two balls follow the same trajectory

EXAMPLE RESPONSE
$D = v_0\sqrt{2H/g}$ depends only on v_0, H and g. None of those changes between the two launches, so the second ball lands the same distance D from the cliff.

MINIMUM SUFFICIENT Pointing at the derived expression and saying it has no mass in it — "no m in $D = v_0\sqrt{2H/g}$" is enough. **Not enough:** stopping at "both have the same acceleration." That is B2. This point is paid for reaching the distance.

Problem 1.2: Translation Between Representations (TBR) — 12 rubric points

The problem. Two carts start together at $x = 0$ at $t = 0$ on a straight horizontal track. Cart A moves right at constant velocity v_A. Cart B starts from rest and accelerates uniformly to the right at a_B.

Part (a) *Draw a motion diagram for Cart B: at least five dots at equally spaced times, with a velocity vector at each dot.*

For at least five dots whose gaps grow from one interval to the next. **Point A1**

Scoring Note. Judge the trend, not the arithmetic. Any diagram in which the gaps visibly widen earns it. Equally spaced dots do not, at any spacing — equal spacing is the picture of constant velocity, which is Cart A.

EXAMPLE RESPONSE

Six dots with gaps in roughly the ratio $1 : 3 : 5 : 7 : 9$.

MINIMUM SUFFICIENT Five dots a reader can see are getting further apart. No ratios, no numbers, no labels.

For a velocity vector at each dot after the first, every one pointing in the direction of travel. **Point A2**

Scoring Note. The dot at $t = 0$ may carry no vector, or a vector of zero length, because the cart starts from rest; a short vector drawn there does not cost the point so long as every other vector points correctly.

EXAMPLE RESPONSE

An arrow above every dot after the first, each pointing right, in the direction the cart travels. The dot at $t = 0$ is left bare.

MINIMUM SUFFICIENT An arrow at each dot, all pointing the same way as the motion. **Not enough:** one arrow drawn once for the whole diagram. The question asks for a vector *at each dot*, and a single arrow does not show how the velocity changes.

For velocity vectors that lengthen from dot to dot. **Point A3**

EXAMPLE RESPONSE

Five right-pointing arrows whose lengths grow in the ratio $1 : 2 : 3 : 4 : 5$.

MINIMUM SUFFICIENT Each arrow visibly longer than the one before it. **Not enough:** arrows of equal length, even when the dot spacing is right. The spacing and the arrow lengths are two separate claims about the motion, and the diagram has to make both.

Part (b) i *Derive an expression for the time t_m at which Cart B has the same speed as Cart A, beginning from a fundamental principle or a reference equation.*

For opening with a constant-acceleration relation between velocity and time. **Point B1**

Accept one of the following:

- $v = v_0 + at$
- $v_B = a_B t$
- $a_B = \Delta v/\Delta t$

EXAMPLE RESPONSE

$v = v_0 + at$. Cart B starts from rest, so $v_0 = 0$ and $v_B(t) = a_B t$.

MINIMUM SUFFICIENT Any of those three equations on the page. **Not enough:** naming it in words with no equation written down.

For setting Cart B's speed equal to v_A at the time being solved for. **Point B2**

EXAMPLE RESPONSE

$v_A = a_B t_m$

MINIMUM SUFFICIENT The equation $v_A = a_B t_m$. **Not enough:** the sentence "the speeds are equal" without the equation — the question asks for a derivation, and that begins where the condition becomes algebra.

For the correct expression $t_m = v_A/a_B$. **Point B3**

Scoring Note. The answer on its own carries B2 with it — $t_m = v_A/a_B$ is $v_A = a_B t_m$ rearranged, and writing one is writing the other. B1 is not carried: nothing on the page then shows which relation the student started from.

EXAMPLE RESPONSE

$$t_m = \frac{v_A}{a_B}$$

MINIMUM SUFFICIENT $t_m = v_A/a_B$.

Part (b) ii *Derive an expression for the time t_c at which Cart B is first back level with Cart A after $t = 0$.*

For setting position expressions for the two carts equal, with Cart B's carrying the $\frac{1}{2}a_B t^2$ term. **Point B4**

EXAMPLE RESPONSE

$$v_A t_c = \tfrac{1}{2} a_B t_c^2$$

MINIMUM SUFFICIENT The equation $v_A t = \frac{1}{2} a_B t^2$. **Not enough:** writing the two position functions one under the other and never setting them equal. Catching up *is* the equality, and that step is what this point pays for.

For the correct nonzero solution $t_c = 2v_A/a_B$. **Point B5**

Scoring Note. $t_c = 0$ solves the equation in B4 as well, but it is the start, not the catch-up. A response that offers only $t = 0$ earns B4 and not B5.

EXAMPLE RESPONSE

Both sides carry a factor t_c, and after the start $t_c \neq 0$, so it divides out: $v_A = \frac{1}{2} a_B t_c$, giving $t_c = \dfrac{2v_A}{a_B}$.

MINIMUM SUFFICIENT $t_c = 2v_A/a_B$. The rejected root need not be mentioned.

Part (c) *Sketch x against t for both carts from $t = 0$ to a time beyond t_c, labelling each curve.*

For Cart A drawn as a straight line from the origin rising at a constant slope, labelled A. **Point C1**

EXAMPLE RESPONSE

A straight line from the origin climbing at a constant slope, with the letter A written beside its upper end.

MINIMUM SUFFICIENT One straight line starting at the origin and going up, with the letter A on or beside it. No scale, no numbers, no axis values.

For Cart B drawn as a curve from the origin that starts flat and steepens all the way, labelled B. **Point C2**

Scoring Note. Judge the curvature, not the algebra. Any curve leaving the origin along — or nearly along — the time axis and bending upward earns it.

EXAMPLE RESPONSE

A parabola through the origin with zero initial slope, crossing line A once at a later time and staying above it afterwards, labelled B.

MINIMUM SUFFICIENT A curve from the origin that is visibly getting steeper, labelled B. **Not enough:** a straight line for Cart B at any slope — a straight x–t graph says the acceleration is zero. **Also not enough:** a curve that starts steep and flattens, which is the picture of a cart slowing down.

Part (d) *At t_m, is Cart B ahead of, behind, or level with Cart A? Justify by referring to the graphs sketched in part (c).*

For selecting "Behind Cart A." **Point D1**

EXAMPLE RESPONSE

Behind Cart A. (The wrong selection is *At the same position* — equal speeds read as equal positions.)

MINIMUM SUFFICIENT The blank under "Behind Cart A" marked. Scored on its own.

For a justification that reads the relative position off the sketched graphs: at t_m the line for Cart A lies above the curve for Cart B. **Point D2**

Accept one of the following:

- at t_m curve B is below line A, and a higher point on an x–t graph is a position further along the track
- the two graphs have the same slope at t_m but different heights, with B's the lower
- the graphs meet again only at t_c, which comes later than t_m, so at t_m Cart B has not caught up yet

Scoring Note. The question asks for the justification to come from the graphs, so that is what is scored. An algebraic comparison of $x_A(t_m)$ and $x_B(t_m)$ with no reference to the sketch is correct physics in the wrong currency and does not earn this point — the whole subject of the problem is reading motion off a representation.

EXAMPLE RESPONSE

At t_m the tangent to curve B is parallel to line A, so the speeds match — but curve B is still below line A. The vertical axis is position, so Cart B is behind. The two do not meet again until t_c.

MINIMUM SUFFICIENT "At t_m, B is below A on the graph," in those words or drawn on the sketch as a marked gap between the two curves at t_m. **Not enough:** "Cart B was slower for the whole time before that." True, and it is an argument from speed rather than from the graph the question points at.

Problem 1.3: Experimental Design and Analysis (LAB) — 10 rubric points

The problem. Students determine the acceleration of a cart released from rest down a ramp at a fixed angle θ, using a low-friction cart, a ramp of adjustable length, a meterstick, an electronic stopwatch and tape. A second experiment supplies a table of distance d against time t: $(0.20,\ 0.46)$, $(0.40,\ 0.64)$, $(0.60,\ 0.76)$, $(0.80,\ 0.91)$, $(1.00,\ 1.01)$, in metres and seconds, with an empty third column for t^2.

Part (a) *Describe a procedure for collecting the data needed to find the acceleration, including any step that reduces uncertainty.*

For a procedure that states both which distance is measured and how the matching time is measured, at more than one distance. **Point A1**

> **EXAMPLE RESPONSE**
> Mark positions along the ramp with tape and measure each distance d from a fixed release line with the meterstick. Hold the cart at the line, release it from rest without a push, and start the stopwatch at the moment of release; stop it as the cart passes the mark. Repeat at each marked distance.

MINIMUM SUFFICIENT Two sentences that name the meterstick for d and the stopwatch for t, plus any wording showing that d is varied — "for several distances", "repeat at $0.40\,\text{m}$, $0.60\,\text{m}\ldots$" is enough. **Not enough:** a procedure that times a single distance. One point fixes no slope.

For a step that would genuinely reduce the uncertainty in the result. **Point A2**

Accept one of the following:

- repeat the timing at each distance and take the mean
- use the longest distances available, so the measured times are large compared with the reaction time
- release from rest at the same marked line each run, with no push

Scoring Note. "Be careful", "measure accurately" and "avoid mistakes" are not procedures and earn nothing. The test is whether a second student could carry the instruction out.

> **EXAMPLE RESPONSE**
> Time each distance at least three times and use the average. Averaging suppresses the random scatter from starting and stopping the watch by hand, which is the dominant uncertainty with a hand-held stopwatch.

MINIMUM SUFFICIENT The words "repeat" and "average" (or "several trials … mean") attached to the *timing*. Naming the source of the uncertainty is not required, though it is what the sentence is worth reading for.

Part (b) *Describe how the data could be graphed and how that graph would be analysed to find the acceleration.*

For naming a pair of plotted quantities that gives a straight line. **Point B1**

Accept one of the following:

- d on one axis against t^2 on the other
- t^2 against d
- any pair with the same functional relationship, such as d against $\frac{1}{2}t^2$

Scoring Note. Which quantity goes on which axis is not scored here, and this point can be earned with part (a) blank.

> **EXAMPLE RESPONSE**
> Plot d on the vertical axis against t^2 on the horizontal axis. Since $d = \frac{1}{2}at^2$, the result is a straight line through the origin.

MINIMUM SUFFICIENT The pair "d and t^2" named. **Not enough:** "graph the data", or "plot d against t" — the second is a curve, and the whole move being tested is the one that straightens it.

For stating how the slope of that line yields the acceleration. **Point B2**

EXAMPLE RESPONSE
The slope equals $\frac{1}{2}a$, so the acceleration is twice the slope.

MINIMUM SUFFICIENT "$a = 2\times$ slope", or "slope $= a/2$". **Not enough:** "the slope gives the acceleration." The factor of two is the content of the point; without it the sentence is true of any linearisation and says nothing about this one.

Part (c) i *Name two quantities that, graphed, give a straight line whose slope yields the acceleration, and complete the t^2 column.*

For naming, in the two blanks, a pair of quantities that produces such a line. **Point C1**

Scoring Note. The third column of the table is not scored separately. Its values are checked through C3, where the points are plotted.

EXAMPLE RESPONSE
Vertical axis: d (m). Horizontal axis: t^2 (s^2). Third column: 0.21, 0.41, 0.58, 0.83, 1.02.

MINIMUM SUFFICIENT "d" in one blank and "t^2" in the other, in either order. Units are not required here — they are scored at C2 — and "distance" and "time squared" in words are equally acceptable.

Part (c) ii *Plot the data on the grid, label the axes with names, units and a scale, and draw a straight best-fit line.*

For labelling both axes with the quantity and its unit, and numbering them on a linear scale. **Point C2**

EXAMPLE RESPONSE
Horizontal axis "t^2 (s^2)" numbered 0 to 1.2 in steps of 0.2; vertical axis "d (m)" numbered the same way.

MINIMUM SUFFICIENT Both axes carrying a name and a unit, and at least two numbers on each from which the spacing can be read. **Not enough:** a named axis with no unit, or numbers whose spacing is uneven — a non-linear scale makes the slope meaningless.

For plotting all five points where the student's own axes and t^2 values put them. **Point C3**

Scoring Note. Score against the axes the student actually drew and the squares they actually computed. A student who mislabels an axis but plots consistently with that label keeps this point.

EXAMPLE RESPONSE
Five marks at $(0.21,\ 0.20)$, $(0.41,\ 0.40)$, $(0.58,\ 0.60)$, $(0.83,\ 0.80)$ and $(1.02,\ 1.00)$, on axes running from 0 to 1.2.

MINIMUM SUFFICIENT Five marks on the grid, each within about half a grid square of where the student's own numbers put it. **Not enough:** four points. The point is for the data set, not for the technique.

For one straight line drawn through the trend of the plotted points. **Point C4**

Scoring Note. The line need not pass through the origin or through any particular point. What is scored is that it is a single straight line lying among the data.

EXAMPLE RESPONSE
A single straight line ruled from near the origin up through the cloud of points, with points falling on both sides of it rather than all on one side.

MINIMUM SUFFICIENT One straight line with points on both sides of it. **Not enough:** segments drawn from dot to dot. That is a record of the scatter, not a model of the trend, and it has no single slope to measure.

Part (d) *Using the best-fit line, calculate an experimental value for the acceleration, showing how the slope was found from two points on the line rather than two data points.*

For a slope computed from two points lying on the drawn line. Point D1

EXAMPLE RESPONSE

Reading $(0.10\,\mathrm{s}^2,\ 0.10\,\mathrm{m})$ and $(1.10\,\mathrm{s}^2,\ 1.08\,\mathrm{m})$ off the line, slope $= \dfrac{1.08\,\mathrm{m} - 0.10\,\mathrm{m}}{1.10\,\mathrm{s}^2 - 0.10\,\mathrm{s}^2} = 0.98\,\mathrm{m/s}^2$.

MINIMUM SUFFICIENT Two coordinate pairs marked on the line, and a subtraction of the form $(y_2 - y_1)/(x_2 - x_1)$ using them. **Not enough:** two of the five table values, even when they happen to sit on the line. The question asks for points on the line, and the distinction is the reason the subpart exists — a data point carries its own scatter, a point on the line does not.

For turning that slope into an acceleration by doubling it, and reporting a value near $2\,\mathrm{m/s}^2$. Point D2

Scoring Note. Accept $1.8\,\mathrm{m/s}^2$ to $2.2\,\mathrm{m/s}^2$, which covers the spread of reasonable hand-drawn best-fit lines. Score consistently: a wrong slope correctly doubled earns the point.

EXAMPLE RESPONSE

$a = 2 \times \text{slope} = 2(0.98\,\mathrm{m/s}^2) \approx 2.0\,\mathrm{m/s}^2$

MINIMUM SUFFICIENT The line "$a = 2 \times \text{slope} = \ldots$" with a number and the unit $\mathrm{m/s}^2$. **Not enough:** reporting the slope itself as the acceleration. It has the right units, which is exactly why the error survives to the end of the paper.

Problem 1.4: Qualitative Quantitative Translation (QQT) — 8 rubric points

The problem. A ball thrown straight up from the ground at speed v_0 reaches a maximum height h_1 (Trial 1). Thrown from the same place at $2v_0$, it reaches h_2 (Trial 2). Air resistance is negligible in both.

Part (a) *Is h_2 greater than, less than, or equal to $2h_1$? Justify in terms of the motion, using reasoning beyond a reference to equations.*

For selecting $h_2 > 2h_1$. **Point A1**

EXAMPLE RESPONSE

$h_2 > 2h_1$. (The wrong selection is $h_2 = 2h_1$ — double the speed, double the height.)

MINIMUM SUFFICIENT The blank under $h_2 > 2h_1$ marked. Scored on its own.

For a justification identifying that the rise takes twice as long, because the deceleration is the same in both trials. **Point A2**

EXAMPLE RESPONSE

Gravity takes speed away at the same rate in both trials. Twice the launch speed therefore needs twice as long to be brought to zero, so the ball in Trial 2 is rising for twice as long.

MINIMUM SUFFICIENT "Same g, so twice the speed takes twice the time to stop." **Not enough:** "it goes up for longer" with nothing tying it to the unchanged deceleration. The unchanged deceleration is what makes the time scale exactly, and "longer" by itself is also true of the wrong answer.

For a justification identifying that the average speed during the rise doubles as well, so that the height grows by a factor of four. **Point A3**

Scoring Note. The question asks for reasoning beyond the equations, so a response that only substitutes into $h = v_0^2/2g$ earns nothing here. That work is scored in part (b), where it is what was asked for.

EXAMPLE RESPONSE

The ball in Trial 2 is also moving twice as fast on average while it climbs. Twice the average speed for twice the time is four times the distance, so $h_2 = 4h_1$, which is more than $2h_1$.

MINIMUM SUFFICIENT "Twice the average speed and twice the time, so four times the height" — or any wording that multiplies the two doublings into a factor of four. **Not enough:** "it goes more than twice as high." That restates the claim of part (a) instead of arriving at it.

Part (b) *Starting from a kinematic equation in the reference information, derive an expression for the maximum height h reached by a ball thrown straight up at speed v_0.*

For opening with a kinematic relation linking velocity, acceleration and displacement. **Point B1**

Accept one of the following:

- $v^2 = v_0^2 + 2a\,\Delta y$
- $v^2 = v_0^2 + 2a\,(y - y_0)$
- $v = v_0 + at$ together with $\Delta y = v_0 t + \frac{1}{2}at^2$

Scoring Note. The third route is longer but reaches the same place, and the question does not name an equation. Do not penalise it.

EXAMPLE RESPONSE

$v^2 = v_0^2 + 2a\,\Delta y$, copied from the reference information, with up taken as positive.

MINIMUM SUFFICIENT One of those equations on the page before anything is substituted into it.

For the substitutions that pin the top of the flight: zero velocity there, and an acceleration of magnitude g opposing the motion. **Point B2**

EXAMPLE RESPONSE

$0 = v_0^2 + 2(-g)h$

MINIMUM SUFFICIENT $0 = v_0^2 - 2gh$ written down. **Not enough:** leaving the final velocity as a symbol v, or writing $a = +g$ with up taken as positive. Setting $v = 0$ *is* the statement that this is the top of the flight, and without it nothing in the algebra says which height is being found.

For the correct expression $h = v_0^2/(2g)$. **Point B3**

Scoring Note. An unsupported $h = v_0^2/(2g)$ carries B2 too, since the expression cannot be reached without setting the velocity at the top to zero. B1 stays unearned: the question names the reference information as the starting place, and a response that shows no working never visits it.

EXAMPLE RESPONSE

$2gh = v_0^2$, so $h = \dfrac{v_0^2}{2g}$.

MINIMUM SUFFICIENT $h = v_0^2/(2g)$.

Part (c) *Is the expression from part (b) consistent with the claim in part (a)? Justify by referring to specific terms or to the functional dependence in the expression.*

For selecting "Consistent." **Point C1**

EXAMPLE RESPONSE

Consistent. Part (b) gives a height going as v_0^2, and part (a) claimed more than double; the two agree.

MINIMUM SUFFICIENT The blank under "Consistent" marked. Scored on its own.

For a justification that uses the functional dependence in the derived expression to reach the factor of four. **Point C2**

EXAMPLE RESPONSE

In $h = v_0^2/(2g)$ the height goes as the square of the launch speed, since v_0^2 sits in the numerator and g is a constant. Doubling v_0 therefore multiplies h by $2^2 = 4$, and $4h_1$ is greater than $2h_1$ — which is the claim made in part (a).

MINIMUM SUFFICIENT "$h \propto v_0^2$, so doubling v_0 gives $4h_1 > 2h_1$." **Not enough:** "h depends on v_0^2" and nothing further — the dependence has to be carried to the comparison the question asked about. **Also not enough:** "yes, it agrees." Two of the eight points on a question of this type live in part (c), and a single sentence of agreement collects one of them.

Problem 1.5: Translation Between Representations (TBR) — 12 rubric points

The problem. A walkway of length L moves to the right at constant speed $v_{W/G}$ relative to the ground. At $t = 0$ a student at the right end starts walking to the left at constant speed $v_{S/W}$ relative to the walkway, with $v_{W/G} > v_{S/W}$. Observer A stands on the ground; Observer B rides the walkway.

Part (a) *On each observer's number line, draw and label an arrow for the student's velocity; on Observer A's line, also draw the walkway's velocity.*

For a rightward arrow on Observer A's number line, labelled as the walkway's velocity. **Point A1**

EXAMPLE RESPONSE
On Observer A's line, an arrow from the dot pointing toward $+x$, labelled $v_{W/G}$.

MINIMUM SUFFICIENT An arrow from the dot toward $+x$ with "$v_{W/G}$" or "walkway" beside it. **Not enough:** an unlabelled arrow — with three velocities in this problem, an unlabelled arrow names none of them.

For a rightward arrow on Observer A's number line for the student, drawn shorter than the walkway's. **Point A2**

Scoring Note. Both conditions belong to this one point. An arrow of the right length pointing the wrong way earns nothing here, and neither does a correctly directed arrow as long as the walkway's.

EXAMPLE RESPONSE
An arrow for the student pointing $+x$, roughly half the length of the walkway arrow, labelled $v_{S/G}$.

MINIMUM SUFFICIENT A labelled student arrow pointing right and visibly shorter than the walkway arrow on the same line. **Not enough:** a leftward arrow. The student walks left relative to the *walkway*, but the walkway outruns them, so the ground sees them drift right.

For a leftward arrow on Observer B's number line for the student. **Point A3**

EXAMPLE RESPONSE
On Observer B's line, an arrow from the dot pointing toward $-x$, labelled $v_{S/W}$.

MINIMUM SUFFICIENT An arrow from the dot toward $-x$, labelled for the student or as $v_{S/W}$. Its length is not scored — there is nothing on that line to compare it with.

Part (b) i *Derive an expression for the time t_L at which the student reaches the left end of the walkway, beginning from a fundamental principle or a reference equation.*

For opening from a constant-velocity relation applied in the walkway's frame. **Point B1**

Accept one of the following:

- $x_f = x_i + v_x t$ with the student's speed relative to the walkway
- $\Delta x = v\,\Delta t$ with $\Delta x = L$ and $v = v_{S/W}$
- $v_{S/W} = L/t_L$

Scoring Note. What is scored is the use of $v_{S/W}$ rather than a ground-frame speed. L is a length *of the walkway*, so the crossing time is fixed in the walkway's frame.

EXAMPLE RESPONSE
Put $x = 0$ at the left end of the walkway. The student starts at $x_i = L$ and walks toward $-x$ at $v_{S/W}$ relative to it, so $x_f = x_i + v_x t$ becomes $0 = L - v_{S/W}\, t_L$.

MINIMUM SUFFICIENT An equation in which L and $v_{S/W}$ appear together and no ground-frame speed appears.

For the correct expression $t_L = L/v_{S/W}$. **Point B2**

EXAMPLE RESPONSE

$v_{S/W}\, t_L = L$, so $t_L = \dfrac{L}{v_{S/W}}$.

MINIMUM SUFFICIENT $t_L = L/v_{S/W}$. **Not enough:** $L/(v_{W/G} - v_{S/W})$. That is how long the student would take to cover a ground distance L, which is not what the walkway's left end is.

Part (b) ii *From the given relation $\Delta x_{S/G} = \Delta x_{S/W} + \Delta x_{W/G}$, derive an expression for the student's velocity $v_{S/G}$ relative to the ground.*

For dividing the given displacement relation by the time interval to reach a relation between velocities. **Point B3**

EXAMPLE RESPONSE

$\dfrac{\Delta x_{S/G}}{\Delta t} = \dfrac{\Delta x_{S/W}}{\Delta t} + \dfrac{\Delta x_{W/G}}{\Delta t}$, so $v_{S/G} = v_{S/W,x} + v_{W/G}$.

MINIMUM SUFFICIENT The three-term velocity equation written down, however it was reached. **Not enough:** copying the displacement relation out unchanged — the question supplies that line, so reproducing it adds nothing.

For applying the sign of the student's velocity relative to the walkway and reaching $v_{S/G} = v_{W/G} - v_{S/W}$. **Point B4**

Scoring Note. The minus sign is the physics of this subpart. A response that adds the two speeds earns B3 and not B4.

EXAMPLE RESPONSE

The student walks toward $-x$ relative to the walkway, so $v_{S/W,x} = -v_{S/W}$ and $v_{S/G} = -v_{S/W} + v_{W/G} = v_{W/G} - v_{S/W}$. Because $v_{W/G} > v_{S/W}$ this is positive: the ground still sees the student drift right.

MINIMUM SUFFICIENT $v_{S/G} = v_{W/G} - v_{S/W}$.

Part (b) iii *Derive an expression for the student's displacement $\Delta x_{S/G}$ relative to the ground, from $t = 0$ until they reach the left end.*

For a displacement built from the ground-frame velocity and the crossing time, consistent with the two results above. **Point B5**

Scoring Note. This single point covers both the relation and the substitution, so it needs both: a bare final expression with no product visible does not show that the walkway's own motion was accounted for. Score for consistency — a wrong $v_{S/G}$ or t_L carried correctly into $\Delta x = vt$ still earns it.

EXAMPLE RESPONSE

$$\Delta x_{S/G} = v_{S/G}\, t_L = (v_{W/G} - v_{S/W})\left(\frac{L}{v_{S/W}}\right) = L\left(\frac{v_{W/G}}{v_{S/W}} - 1\right)$$

MINIMUM SUFFICIENT The product $(v_{W/G} - v_{S/W}) \times L/v_{S/W}$ on the page, in any algebraically equivalent form; it need not be simplified. **Not enough:** $\pm L$. The student reaches the left end of a walkway that has itself been moving the whole time, so the ground-frame displacement is not the walkway's length.

Part (c) *Sketch the student's position against time from $t = 0$ to $t = t_L$ as measured by each observer, labelling each graph.*

For Observer A's graph: a straight line with positive slope, labelled A. **Point C1**

EXAMPLE RESPONSE

A straight line climbing steadily from left to right across the whole interval 0 to t_L, labelled A.

MINIMUM SUFFICIENT One straight rising line, labelled A. No numbers, no intercept, no scale.

For Observer B's graph: a straight line with negative slope, labelled B.

Point C2

Scoring Note. Only the linearity and the sign of the slope are scored. The intercepts are not: a student may put the origin at either end of the walkway, and both choices are right.

EXAMPLE RESPONSE

A straight line falling from its starting height and meeting the time axis at $t = t_L$, labelled B.

MINIMUM SUFFICIENT One straight falling line, labelled B. **Not enough:** a curve in either graph. Each observer measures a constant velocity, and a constant velocity is a straight line.

Part (d) *A student claims that because the two observers measure different velocities, they must measure different accelerations. Is the claim correct? Justify by referring to the representations in parts (a) and (c).*

For indicating that the claim is not correct.

Point D1

EXAMPLE RESPONSE

Incorrect.

MINIMUM SUFFICIENT "Incorrect", "no", or the corresponding blank marked. Scored on its own.

For a justification that both observers measure zero acceleration, resting on the straight lines of part (c) or the single unchanging arrows of part (a).

Point D2

Accept one of the following:

- both graphs in part (c) are straight, so both slopes are constant, so both accelerations are zero
- each observer assigns the student one unchanging velocity arrow, so neither sees the velocity change
- the two frames differ by a constant velocity, which shifts the slope of the graph without curving it

EXAMPLE RESPONSE

Both position–time graphs are straight lines, so each observer measures a constant velocity — a different one, but constant. Constant velocity means zero acceleration, so the two observers measure the same acceleration, namely zero, and the claim is wrong.

MINIMUM SUFFICIENT "Both graphs are straight lines, so both accelerations are zero." **Not enough:** "the accelerations are the same" with nothing said about how the representation shows it. The question asks for the justification to come from parts (a) and (c), and that is where the answer is visible.

Tally sheet

One column per problem, one box per point. Photocopy it, or keep one on the desk and write the student's name at the top. The short labels are reminders, not the rubric — the ruling for each point is on its own page above.

1.1 MR 10 pts

- ☐ **A1** FBD: one labelled arrow down, nothing else
- ☐ **A2** opens with $y = y_0 + v_{y0}t + \frac{1}{2}a_y t^2$
- ☐ **A3** $v_{y0} = 0$ and $|\Delta y| = H$
- ☐ **A4** $t = \sqrt{2H/g}$
- ☐ **A5** $D = v_0 t$
- ☐ **A6** $D = v_0\sqrt{2H/g}$
- ☐ **A7** $D \approx 36$ m, with unit
- ☐ **B1** "Equal to"
- ☐ **B2** $a = mg/m = g$
- ☐ **B3** no mass in the expression for D

1.2 TBR 12 pts

- ☐ **A1** 5+ dots, gaps widening
- ☐ **A2** a vector at each dot, all forward
- ☐ **A3** vectors lengthening
- ☐ **B1** opens with $v = v_0 + at$
- ☐ **B2** $v_A = a_B t_m$
- ☐ **B3** $t_m = v_A/a_B$
- ☐ **B4** $v_A t_c = \frac{1}{2}a_B t_c^2$
- ☐ **B5** $t_c = 2v_A/a_B$
- ☐ **C1** A: straight line from origin, labelled
- ☐ **C2** B: curve from origin, steepening, labelled
- ☐ **D1** "Behind Cart A"
- ☐ **D2** at t_m, B below A *on the graph*

1.3 LAB 10 pts

- ☐ **A1** measures d and t, at several d
- ☐ **A2** a real uncertainty-reducing step
- ☐ **B1** names d against t^2
- ☐ **B2** $a = 2\times$ slope
- ☐ **C1** d and t^2 in the blanks
- ☐ **C2** both axes: name, unit, linear scale
- ☐ **C3** all five points plotted
- ☐ **C4** one straight best-fit line
- ☐ **D1** slope from two points *on the line*
- ☐ **D2** a between 1.8 and 2.2 m/s^2

1.4 QQT 8 pts

- ☐ **A1** $h_2 > 2h_1$
- ☐ **A2** same g, so twice the rise time
- ☐ **A3** average speed doubles too ⇒ $4\times$
- ☐ **B1** opens with $v^2 = v_0^2 + 2a\Delta y$
- ☐ **B2** $0 = v_0^2 - 2gh$
- ☐ **B3** $h = v_0^2/2g$
- ☐ **C1** "Consistent"
- ☐ **C2** $h \propto v_0^2 \Rightarrow 4h_1 > 2h_1$

1.5 TBR 12 pts

- ☐ **A1** A's line: walkway arrow right, labelled
- ☐ **A2** A's line: student arrow right, shorter
- ☐ **A3** B's line: student arrow left
- ☐ **B1** uses $v_{S/W}$ with L, not a ground speed
- ☐ **B2** $t_L = L/v_{S/W}$
- ☐ **B3** divides by Δt to get velocities
- ☐ **B4** $v_{S/G} = v_{W/G} - v_{S/W}$
- ☐ **B5** $\Delta x_{S/G} = (v_{W/G} - v_{S/W})L/v_{S/W}$
- ☐ **C1** A: straight line, positive slope
- ☐ **C2** B: straight line, negative slope
- ☐ **D1** claim is incorrect
- ☐ **D2** straight graphs ⇒ both $a = 0$

TOTAL

1.1 ______ / 10
1.2 ______ / 12
1.3 ______ / 10
1.4 ______ / 8
1.5 ______ / 12

______ **/ 52**

Scoring key, Unit 1: Kinematics. Written for *AP Physics 1: Algebra-Based — Practice Workbook*, Chapter 1, problems 1.1–1.5. Original rubrics for original problems, set out in the format of published scoring guidelines. Not a College Board document and not endorsed by College Board.